

Latest Oligocene and Miocene whelks (Gastropoda: Neogastropoda: Buccinidae) from Peru

Thomas J. DeVries¹

Burke Museum of Natural History and Culture
University of Washington
Seattle, WA 98195 USA

ABSTRACT

Misifulgur new genus includes fusiform buccinid gastropods with shells that are notably thin medially between the shoulder and base, have moderately long siphonal canals, spiral cords that are well developed anteriorly but often fade posteriorly, an inner lip without plications, a smooth inner surface of the outer lip, and no axial sculpture other than growth lines. The oldest *Misifulgur*, *M. dockeryi* new species, comes from lower Oligocene deposits in Mississippi. While no later records of *Misifulgur* are known from Gulf Coast states or Central America, *Misifulgur* whelks (i.e., *M. sula* (Olsson, 1931), *M. cruziana* (Olsson, 1932), *M. macneili* new species) are the most commonly preserved neogastropods from the latest Oligocene through middle Miocene on sandy substrates at shelf depths in the Peruvian Faunal Province. The most recent *Misifulgur*, *M. montemarensis* new species, lived on protected sandy substrates along the coast of southern Peru during the late Miocene. The late Miocene extinction of *Misifulgur* was contemporaneous with the appearance on the inner shelf of possible competitors, especially muricids of the genus *Chorus* Gray, 1847.

Additional Keywords: Miocene, Mississippi, taxonomy, paleontology, biogeography

INTRODUCTION

The East Pisco Basin was a locus of marine deposition in south-central Peru from the late Eocene until the early Pliocene (DeVries, 1998). Forearc sedimentary strata, which became emergent during the late Pliocene and Quaternary, record shoreface, shallow subtidal, and shelf paleoenvironments (DeVries and Schrader, 1997). Mollusks are abundantly preserved in nearshore deposits and, to a lesser extent, in the medium-grained, bioturbated, and winnowed sandstones associated with inner-shelf water depths. Among neogastropods, the most prominent on the latest Oligocene and Miocene Peruvian shelf were heretofore unrecognized whelks of the family Buccinidae.

The first evidence of late Oligocene–Miocene Peruvian whelks consisted of three incomplete specimens from the Talara and Progreso forearc basins of northern Peru. These gastropods were mischaracterized by Olsson as two species of muricids, *Acanthina* (*Chorus*) *sula* Olsson, 1931 and *Acanthiza* (*Chorus*) *sula cruziana* Olsson, 1932. New fossil whelks from the East Pisco Basin and the more southerly Sacaco Basin, including specimens with intact protoconchs and siphonal canals, show that Peruvian whelks were widely distributed and common in shelf environments throughout the Miocene until they became extinct at about 6 Ma.

The Peruvian whelks are similar to some Paleogene buccinids from the southeastern United States included by MacNeil and Dockery (1984) in the genus *Pseudofulgur* MacNeil, 1984, a taxon comprised of fusiform buccinids from the lower Oligocene Byram Formation of Mississippi. MacNeil's genus has been re-evaluated after examining the Peruvian fossils, type specimens of *Pseudofulgur*, and a new specimen provided by D. Dockery (Office of Geology, Department of Environmental Quality, Mississippi).

GEOLOGY

Onshore outcrops of the Talara Basin in northern Peru extend from the Illescas Mountains (6° S) nearly to the Ecuadorian border (3°45' S). The Progreso Basin passes from northernmost Peru into southwestern Ecuador (Figure 1). Several thousand meters of marginal marine and deeper water sediments accumulated in these forearc basins throughout the Cenozoic (Zuñiga and Cruzado, 1979; Higley, 2004a, 2004b; Martinez et al., 2005). Oligocene and Miocene deposits are especially well developed north of Cabo Blanco (Palacios, 1994). Whelks collected by Olsson (1931) from shallow-water shales at Caleta Mero (3°50' S) were attributed to the basal upper Oligocene or lower Miocene Heath Formation (Olsson, 1931; Engelhardt and Wood, 1993; Higley, 2004a), an assignment consistent with both current geological mapping (Palacios, 1994) and the concurrent presence of *Turritella woodsi* Lisson, 1925 (= *Turritella conquistadorana* Hanna and Israelsky, 1925), which ranges in southern Peru from

¹ Mailing address: Box 13061, Burton, WA 98013 USA.

the late Eocene to latest Oligocene (DeVries, 2007b). A single whelk specimen from Quebrada de la Cruz, a few kilometers east of Caleta Cruz ($3^{\circ}38' S$), was attributed to basal sandstones of the upper Oligocene to lower Miocene lower Zorritos Formation, which, depending on the precise locality, is stratigraphically correlative with or conformably overlying Heath shales (Olsson, 1932). Olsson's (1932) stratigraphic attribution is consistent with current mapping (Palacios, 1994) and age assignments (Higley, 2004b).

The East Pisco Basin (Figure 1) is filled with many hundreds, rather than many thousands of meters of

Cenozoic marine sedimentary rock (Montoya et al., 1993; Leon et al., 2008). Four major depositional sequences are recognized, each associated with an eponymous formation: the Paracas (upper Eocene), Otuma (uppermost Eocene), Chilcatay (uppermost Oligocene to lower middle Miocene), and Pisco (middle Miocene to Pliocene) (DeVries, 1998). Fossil whelks in southern Peru are found in the Chilcatay and Pisco depositional sequences, ranging from the base of the former (about 25 Ma) to the upper half of the latter (about 6 Ma). The most southerly occurrence of Miocene Peruvian whelks is in the Sacaco Basin (Figure 1), situated about 50 km south of

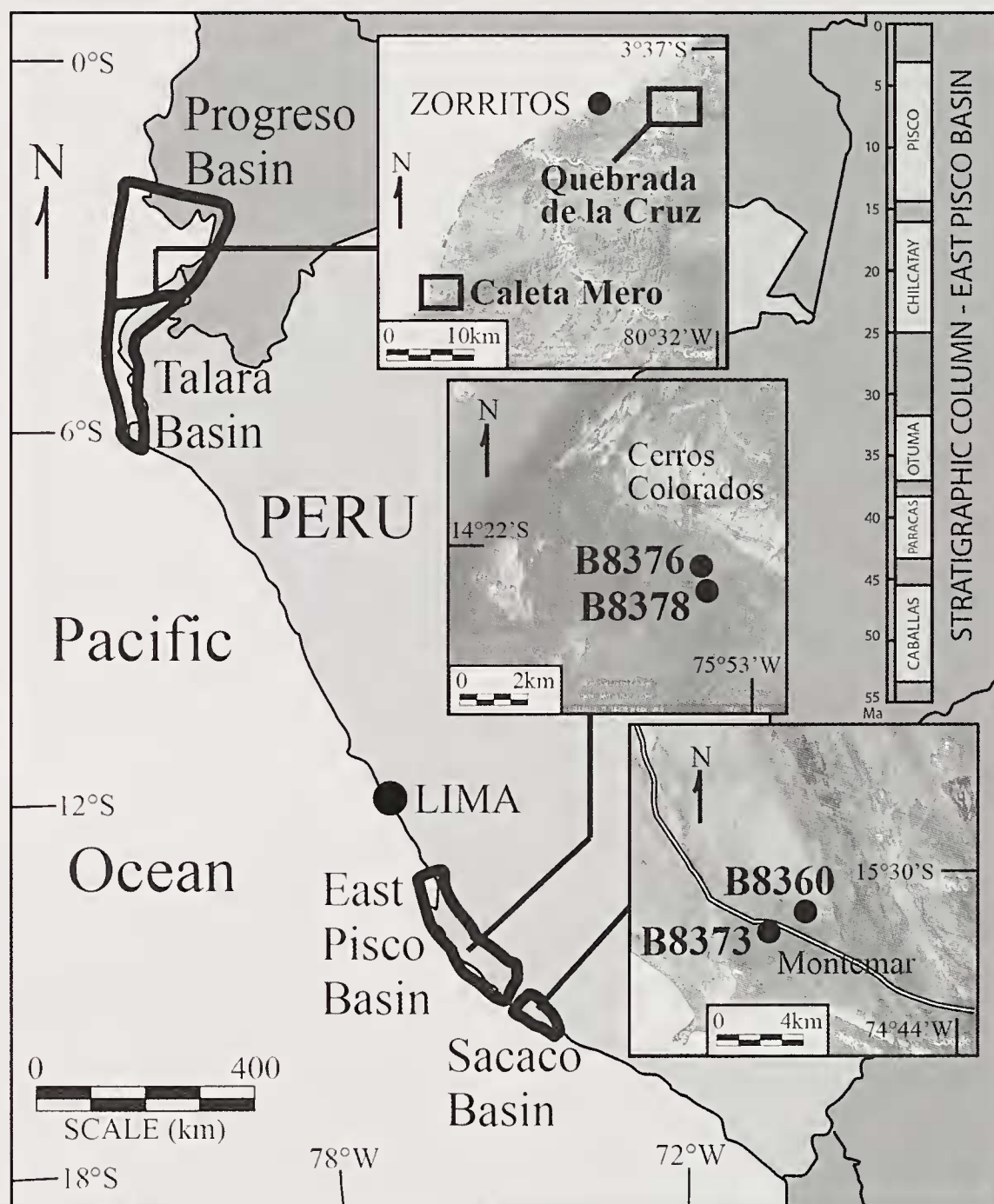


Figure 1. Peruvian Cenozoic forearc basins and type localities of Peruvian species of *Misifulgur*. Progreso and Talara basins after Higley (2004). Upper inset shows type localities of *M. sula* (Olsson, 1931) (Caleta Mero) and *M. cruziana* (Olsson, 1932) (Quebrada de la Cruz). Middle inset shows type locality of *M. macneili* new species (B8376) and a nearby locality (B8378). Lower inset shows type locality of *M. montemarensis* new species (B8360) and a nearby locality (B8373). Inset images are from Google Earth. A stratigraphic column for the Cenozoic section in the East Pisco Basin is shown at upper right.

the East Pisco Basin, where a few hundred meters of inner shelf and nearshore sediments were deposited during the middle to late Miocene and Pliocene (Muizon and DeVries, 1985).

MATERIALS AND METHODS

Specimens from southern Peru were collected by the author. Comparative material was provided by the Academy of Natural Sciences of Philadelphia (Pennsylvania; ANSP), the Office of Geology, Mississippi Department of Environmental Quality (Jackson, Mississippi; MGS), the Paleontological Research Institution (Ithaca, New York; PRI), and the United States National Museum of Natural History (Washington, DC; USNM).

Locality-sample descriptions, listed in the appendix, are designated with a code referencing the author's field notes (DV ××××-××) and a code referencing collections of the University of Washington's Burke Museum of Natural History and Culture (B××××). Lengths (L) and widths (W) are measured in millimeters. Dimensions of broken specimens are enclosed by parentheses. Most figured specimens were coated with ammonium chloride prior to photography. Types and other figured specimens from southern Peru are deposited at the Burke Museum (UWBM) in Seattle and the Laboratorio de Paleontología de Vertebrados, Museo de Historia Natural, Universidad Nacional Mayor de San Marcos (MUSM INV) in Lima, Peru.

SYSTEMATICS

Superfamily Buccinoidea Rafinesque, 1815

Family Buccinidae Rafinesque, 1815

Genus *Misifulgur* new genus

Type Species: *Misifulgur dockeryi* new species. Oligocene, Mississippi.

Diagnosis: Shell fusiform; shell very thin midway between shoulder and base. Protoconch mammillate, paucispiral, smooth, slightly deviated. Axial sculpture of radial orthocone growth lines. Spiral sculpture of primary cords at base, usually becoming weak or obsolete adapically near shoulder. Columellar and parietal calluses absent. Siphonal fasciole obsolete. Inner lip without plications. Inside of outer lip smooth.

Description: Shell medium to large sized, fusiform, very thin medially between shoulder and base. Protoconch mammillate, two to three whorls, smooth, slightly deviated. Spire moderately elevated; sutures variably impressed. Sutural ramp planar, slopes and widths highly variable, marked at shoulder by spiral cord of varying strength. Axial sculpture consisting of radial orthocone growth lines without sutural sinus. Spiral sculpture on smaller whorls with 12 to 20 subequally spaced primary spiral cords;

primary interspaces half as wide to slightly wider than primary cords, U-shaped or flat-bottomed, rarely with a medial secondary spiral cord. Primary spiral cords on later whorls becoming weaker or absent near shoulder and on sutural ramp. Spire whorls with sutural ramp and three to seven primary spiral cords anterior to shoulder. Aperture elongate. Siphonal canal about 20% of shell length, straight to moderately recurved abaxially. Columellar and parietal callus absent; inner lip without plications. Siphonal fasciole obsolete. Inside of outer lip smooth.

Distribution: Early Oligocene, southeastern United States. Late Oligocene to early Miocene, southwestern Ecuador, northern and southern Peru. Middle to late Miocene, southern Peru.

Etymology: 'Misi,' from the native North American Ojibwa word for 'great.'

Remarks: *Misifulgur* new genus includes fusiform Mississippi specimens assigned to *Pseudofulgur* by MacNeil and Dockery (1984) that have flattened spiral cords that fade in prominence posteriorly, a very thin shell medially between shoulder and base, and a smooth inside of the outer lip (Figures 2–5). Excluded are shells that have a lirate and and/or thickened outer lip, a paucispiral mammillate protoconch with closely spaced axial ribs on the last protoconch whorl, and shells with whorls that are not thinned medially, i.e., the holotype of *P. vicksburgensis* (Conrad, 1848) (Figures 6–7), the holotype of *P. lirata* Dockery, 1984, and a new specimen from the Byram Formation of Mississippi referred to *P. lirata* by Dockery (written communication, 2007) (Figures 8, 9), all of which are probably tonnoideans assignable to Ranellidae Gray, 1854 (sensu Beu and Cernohorsky (1986) and Beu (2010)).

Specimens of *Misifulgur* from Mississippi and western South America resemble the ranellids *Linatella caudata* (Gmelin, 1791), a geographically wide-ranging Tethyan cymatiine from the Miocene to the present (Beu, 2010), and *Monoplex weigmanni* (Anton, 1838), a cymatiine with a late Cenozoic Atlantic-Pacific trans-isthmus distribution (Beu, 2010). Shells of both cymatiines, however, are not thinner medially, have a crenulate or lirate inside to the outer lip, exhibit nodulosity at the shoulder that reflects a muted axial sculpture, and on many larger specimens, a callused columella with transverse lirations—all characters absent on specimens of *Misifulgur* of any size.

Modern buccinids and fascioliids from western South America with a moderately elongate siphonal canal (e.g., *Aeneator fontainei* (d'Orbigny, 1839); *Pleuroploca* spp.; *Solenosteira fusiformis* (Blainville, 1832); see Alamo and Valdivieso (1997) for geographic distribution data) have either axial sculpture, a finely lirate inner margin of the outer lip or lirate structure beneath a smooth inside surface of the outer lip, or both. Species of the muricid genus, *Peonza* Oliveira, 1994, resembles the most strongly keeled examples of *Misifulgur cruziana*, but the nodulosity of the spiral cord on the shoulder, the absence of anterior inflation of the last whorl, and a corresponding

presence of a very narrow and elongate siphonal canal easily distinguish the Eocene-to-Miocene Chilean and Argentinian taxon from *Misifulgur*.

The origin of early Oligocene *Misifulgur* and its systematic position with respect to other buccinids remains obscure. The well-constrained morphological variation of American *Misifulgur* from the early Oligocene to late Miocene makes it unlikely that European Eocene and Miocene taxa cited by MacNeil and Dockery (1984: 140) have a close affinity. Pliocene North Pacific buccinids with posteriorly fading spiral cords cited by those authors, e.g., *Chrysodomus stantoni* Arnold, 1908, may be Californian biogeographic outliers of the northwest Pacific genus, *Clinopegma* Grant and Gale, 1931, which has a stubby recurved siphonal canal with a well developed columellar callus and siphonal fasciole (Figure 10). Northern hemisphere buccinids with longer recurved siphonal canals, i.e., many species of *Neptunea* Linné, 1758, have a sutural platform and a strong spiral cord or keel on the shoulder, as do some large specimens of *M. cruziana*. The pattern of spiral cords for all *Neptunea* species, however, does not vary from the spire whorls to the last whorl, whereas on most large specimens of *Misifulgur*, spiral cords anterior to the shoulder on spire whorls fade to obsolescence on the last whorl.

Pseudofulgur and, by extension, Mississippi specimens herein assigned to *Misifulgur* were compared by Dockery (MacNeil and Dockery, 1984: 140) with the late Miocene *Halia americana* Olsson, 1922, from Panama and Costa Rica (Olsson, 1922; Haas, 1942: 310, unfigured, as "*Halia* cf. *americana*"; Woodring, 1964: 290, as *Ampulla americana* (Olsson, 1922), not *Halia* Risso, 1826; Petuch, 2003: 49). With a deep turrid-like sinus close to the suture (Figures 11, 12), Olsson's Costa Rican specimen cannot be placed in the volutid genus, *Ampulla* Röding, 1798, nor in the buccinid genera, *Pseudofulgur* and *Misifulgur*.

Mansfield (1935) doubted Olsson's (1922) attribution of the "*americana*" species to the volutid genus, *Halia*, but saw similarities between Olsson's species and the late Miocene Floridian *Neptunea* (?) *alaquaensis* Mansfield, 1935, including the presence of a sutural sinus (Figures 13, 14). Mansfield's species does have spiral sculpture similar to that of *Pseudofulgur* and *Misifulgur*, but its sutural sinus sets it apart from those genera.

Two northern Peruvian buccinid species assigned herein to *Misifulgur*, *M. sula* (Olsson, 1931) and *M. cruziana* (Olsson, 1932), were placed by their author in the muricid taxon, *Acanthina* (*Chorus*), also spelled *Acanthiza* (*Chorus*). Olsson's gastropods are neither *Acanthina* Fischer von Waldheim, 1807 nor *Chorus* Gray, 1847, both ocenebrine muricids with an anterior external groove and associated enrolled labral tooth (DeVries, 1997, 2003). Specimens of *M. sula* and *M. cruziana* have neither. *Acanthina* (*Chorus*) *meroensis* Olsson, 1931, not assigned herein to *Misifulgur*, was also incorrectly assigned to *Acanthina*; specimens do have an anterior external groove (indeed, two such grooves) and at least one labral tooth, but the square-bottomed groove and spatulate tooth differ from the V-shaped groove and enrolled tooth of *Acanthina*

and *Chorus*. *Acanthiza* (*Chorus*) *solida* (Nelson, 1870) and *Acanthiza* (*Chorus*) *voluta* Olsson, 1932, both Peruvian taxa, are neither *Misifulgur*, *Acanthina*, nor *Chorus*. Olsson's "*voluta*" species has been referred to the pseudolivid genus, *Testallium* Vermeij and DeVries, 1997 (Vermeij, 1998).

Misifulgur dockeryi new species

(Figures 2–5)

Pseudofulgur vicksburgensis (Conrad, 1848).—MacNeil and Dockery, 1984: 141, pl. 32, fig. 5; pl. 52, fig. 13; not pl. 32, fig. 11.

Diagnosis: Shell length to 45 mm. Sutural ramp weakly planar, sloping anteriorly 45 degrees. Spiral sculpture of about 20 broad primary spiral cords between base and shoulder. Secondary spiral threads present on both sides of shoulder inflection.

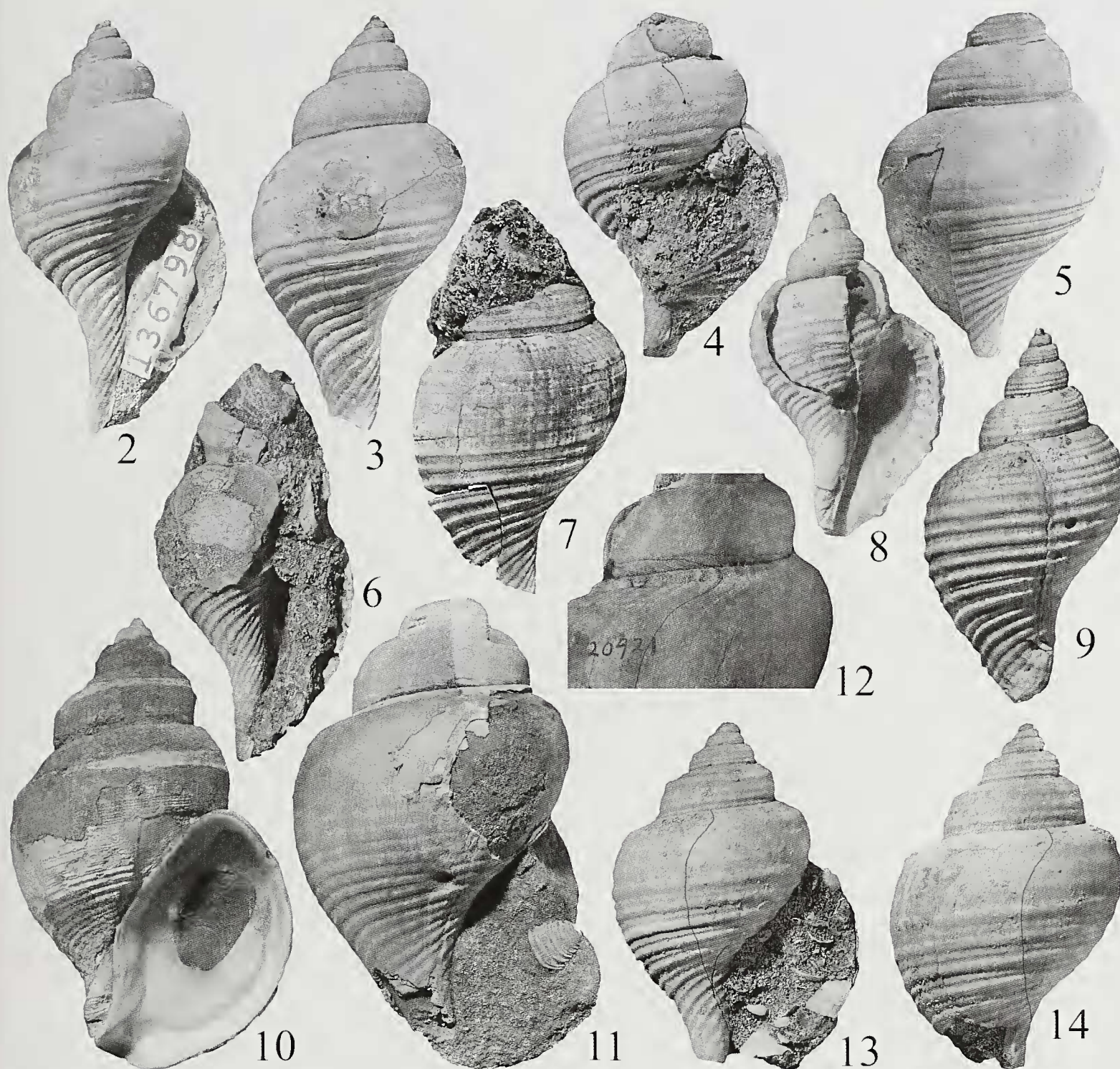
Description: Shell length to 45 mm, fusiform, moderately constricted, inflection two-thirds distance from last-whorl suture to anterior end; very thin medially between shoulder and base. Protoconch unknown. Teleoconch with five to six whorls. Spire moderately elevated; sutures strongly impressed. Sutural ramp weakly planar, sloping anteriorly about 45 degrees from suture, with a weak primary spiral cord at shoulder inflection. Axial sculpture of radial orthocline growth lines, twisted adaperturally at suture. Spiral sculpture of about 20 broad flat-topped primary spiral cords between base and shoulder, subequally spaced, becoming obsolete adapically towards shoulder, replaced in part by closely spaced secondary spiral cords and threads on both sides of shoulder. Primary interspaces half as wide to as wide as primary spiral cords, flat-bottomed, rarely with an intercalated secondary spiral cord or tertiary thread. Spire whorls with sutural ramp, shoulder and four or five prominent primary spiral cords. Aperture elongate, ovate. Siphonal canal 20 percent of shell length, nearly parallel to shell axis, broadly open. Columellar and parietal callus absent. Siphonal fasciole obsolete. Inner lip without plications. Inside of outer lip smooth.

Type Material: MGS 1227, holotype, locality 115, L 22.9, W (15.0). Byram Formation, lower Oligocene.

Type Locality: MGS locality 115, east side Highway 61 across from the Anderson Tully Lumber Company at the boundary of Sections 12 and 35, T.16 N., R.3 E. (MacNeil and Dockery, 1984: 405).

Other Material Examined: USNM 136798, USNM locality 259 (top of bluff, Vicksburg, Warren County, Mississippi), H 42.2, W 21.9. Byram Formation (Marl Member), lower Oligocene.

Distribution: Lower Oligocene, Byram Formation, Mississippi.



Figures 2–14. Gastropods assigned to or compared with *Pseudofulgur* MacNeil, 1984 by MacNeil and Dockery (1984). **2–5.** *Misifulgur dockeryi* new genus new species. Mississippi. Early Oligocene. **2.** USNM 136798. USGS locality 259. Apertural view. Length 42.2 mm. **3.** USNM 136798. Abapertural view. **4.** MGS 1227. MGS locality 115. Holotype, apertural view. Length 22.9 mm. **5.** MGS 1227. Abapertural view. **6–9.** *Pseudofulgur vicksburgensis* (Conrad, 1848). Mississippi. Early Oligocene. **6.** ANSP 13475. Holotype. Apertural view. Length of exposed shell is 21.4 mm. **7.** ANSP 13475. Abapertural view. **8.** MGS 1905. Apertural view. Length 22.4 mm. **9.** MGS 1905. Abapertural view. **10.** *Clinopegma magnum* (Dall, 1895). UWBM 98677. Bering Sea. Recent. Apertural view. Length 71.2 mm. **11, 12.** *Halia americana* Olsson, 1922. PRI 20921. Holotype. Near Mt. Hope, Panama. Late Miocene. **11.** Apertural view. Length 65.4 mm. **12.** Lateral close-up showing sutural sinus, including portion lapping onto penultimate whorl. **13, 14.** *Neptunea* (?) [sic] *alaquaensis* Mansfield, 1935. USNM 373139. Holotype. Station 12046, Vaughan Creek, upper locality, Walton County, Florida. Late Miocene. **13.** Apertural view showing sutural sinus. Length 35 mm. **14.** Abapertural view showing sutural sinus.

Etymology: Named in honor of David T. Dockery, III (Mississippi Office of Geology), in recognition of his work on fossil Cenozoic mollusks of the southeastern United States.

Remarks: Specimens of *Misifulgur dockeryi* new species differ from those of *Pseudofulgur vicksburgensis* in having a thin shell medially between shoulder and base and a smooth inner surface of the outer lip. Specimens of

the latter species have a strongly lirate inner surface of the outer lip and no mid-whorl thinning. Specimens of *M. dockeryi* lack axial sculpture, whereas those of *P. vicksburgensis* have growth lines thickened to the point of becoming low, flat, axial ribs (Figures 7, 9).

Populations of *Misifulgur dockeryi*, as well as *Pseudofulgur* spp., inhabited sandy and muddy substrates on an aggrading continental shelf (Coleman, 1983).

***Misifulgur sula* (Olsson, 1931)**

(Figures 15–18)

Acanthina (*Chorus*) *sula* Olsson, 1931: 107, pl. 18, figs 1, 2.

Diagnosis: Shell fusiform, strongly constricted towards base. Sutural ramp planar to slightly concave, steeply sloping anteriorly from suture. Spire whorls with three or four well-developed spiral cords anterior to shoulder.

Description: Estimated shell length to 50 mm; fusiform, strongly constricted, inflection two-thirds distance from last-whorl suture to anterior end. Shell very thin medially between shoulder and base. Protoconch unknown. Teleoconch with at least three whorls. Spire moderately elongate, sutures moderately impressed. Sutural ramp planar, sloping anteriorly 45 degrees from suture, with low flattened primary spiral cord at shoulder. Axial sculpture of radial orthocline growth lines, bent adaperturally at suture. Spiral sculpture of about 17 primary spiral cords between base and shoulder, posteriormost three cords flattened and weak to obsolete. Sutural ramp smooth. Interspaces flat-bottomed, wider than spiral cords at mid-whorl, lacking intercalated secondary spiral cords. Spire whorls with smooth sutural ramp, prominent shoulder, and three or four strong primary spiral cords anterior to shoulder. Aperture elongate, ovate. Siphonal canal estimated at 20 percent of shell length, narrow, straight or recurved abaxially. Columellar and parietal callus absent. Siphonal fasciole obsolete or weakly developed. Inner lip without plications. Inside of outer lip smooth.

Type Material: PRI 2104, holotype, L (43.3), W 29.0; PRI 2105, paratype, L (27.4), W 18.0.

Type Locality: Caleta Mero, northern Peru (Figure 1, upper inset), early Miocene.

Distribution: Uppermost Oligocene to lower Miocene, Heath and lower Zorritos formations, northern Peru. Lower Miocene, Posorja, Ecuador (Olsson, 1931).

Remarks: Specimens of *Misifulgur sula* are more sharply constricted anteriorly than those of the Gulf coast *M. dockeryi* and the latest Oligocene to early Miocene Peruvian *M. macneili* new species, have a wider sutural platform and more prominent corded shoulder, and have spire whorls with three or four well-developed spiral cords anterior to the shoulder, rather than the four or five of *M. dockeryi* and six or seven of *M. macneili*. The sutural platform is more steeply sloped anteriorly

than most specimens of *M. cruziana*, creating a more fusiform and less turreted profile.

The holotype (PRI 2104) of *Misifulgur sula* has a siphonal canal that is moderately recurved, unlike the paratype (PRI 2105) and specimens assigned to other species of *Misifulgur*, and growth lines on the last whorl of the holotype trace a small sutural sinus that is absent for other species of *Misifulgur*. New material from northern Peru might indicate the need for a taxonomic revision of *M. sula*.

***Misifulgur macneili* new species**

(Figures 19, 20)

Diagnosis: Shell fusiform, moderately constricted towards base. Sutural ramp narrow, planar, steeply sloping anteriorly. Primary spiral cords well developed between base and shoulder. Spire whorls with six or seven spiral cords.

Description: Estimated shell length to 70 mm, fusiform, moderately constricted, inflection two-thirds distance from last-whorl suture to anterior end. Shell thin medially between shoulder and base. Protoconch unknown. Teleoconch with at least five whorls. Spire moderately elongate, sutures moderately impressed. Sutural ramp narrow, sloping anteriorly 60 degrees from suture, with low flattened spiral cord at poorly defined shoulder. Axial sculpture of radial orthocline growth lines, bent adaperturally at suture. Spiral sculpture of about 18 primary spiral cords between base and shoulder, with anterior cords stronger and separated by equally wide interspaces; posterior cords weaker, flattened, and with interspaces half as wide as cords. Some anterior interspaces with an intercalated secondary spiral cord. Spire whorls with smooth, steeply sloping sutural ramp, rounded and poorly defined shoulder, and seven equally strong spiral cords anterior to shoulder. Aperture oval. Siphonal canal estimated at 20 percent of shell length, weakly recurved abaxially. Columellar callus absent; parietal callus not visible. Siphonal fasciole obsolete. Inside of outer lip smooth.

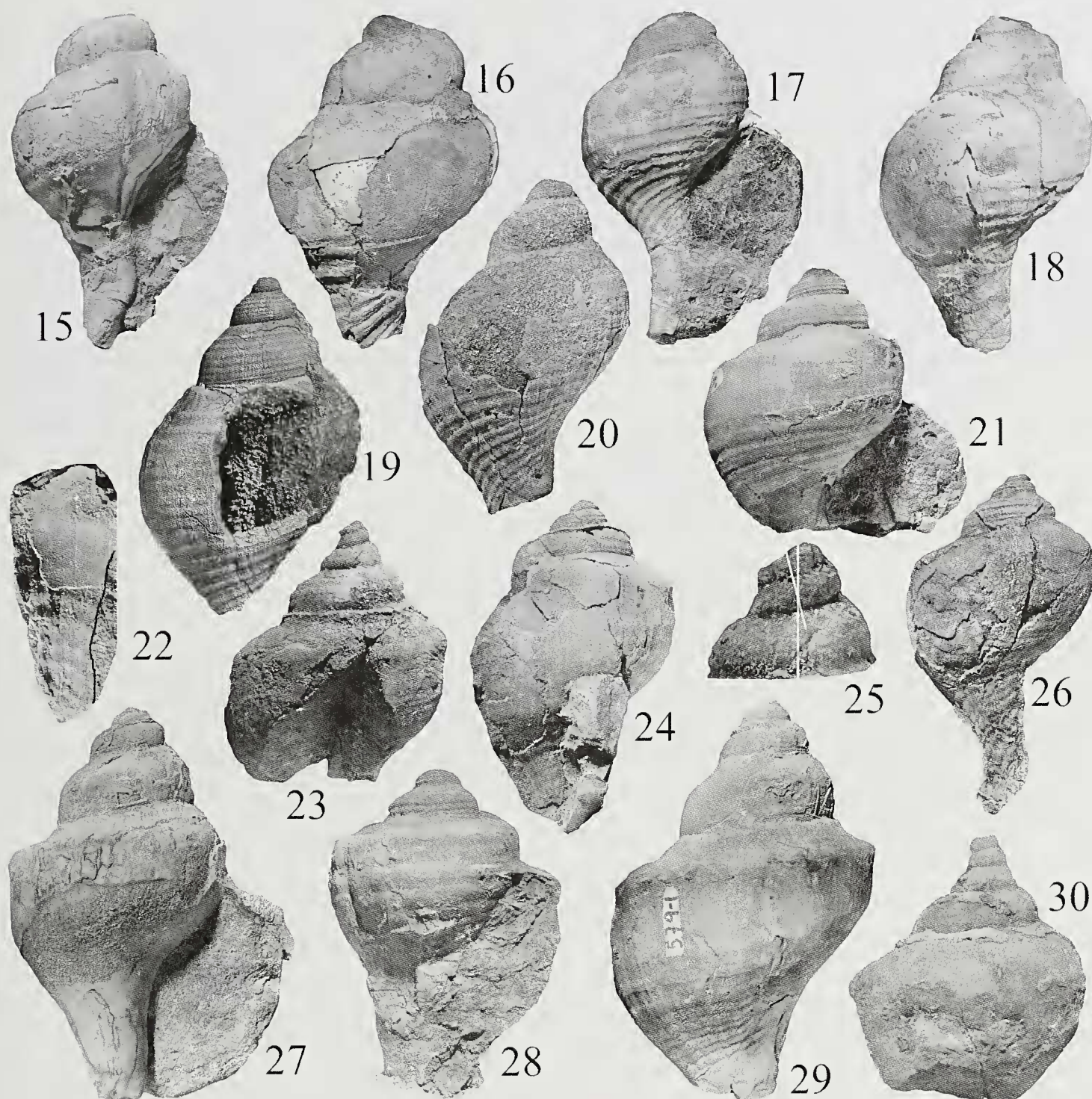
Type Material: UWBM 98670, holotype, B8376 (type locality), L (44.8), W 27.6; UWBM 104229, paratype, B8376, L (30.8); UWBM 104230, paratype, B8378, L (47.2), W 32.0.

Type Locality: B8376, southwest of Cerros Colorados, East Pisco Basin (Figure 1, middle inset), south-central Peru.

Other Material Examined: UWBM 98671, B8358, L (47.6), W (42.4); MUSM INV 200, B8358, L (49.2), W (39.9); B8378, two fragments.

Distribution: Chattian to Burdigalian, Chilcatay depositional sequence, East Pisco Basin, south-central Peru.

Etymology: Named in memory of F. Stearns MacNeil, posthumously a co-author with David T. Dockery of a 1984 study of Oligocene mollusks from Mississippi and author of the genus, *Pseudofulgur*.



Figures 15–30. *Misifulgur* species. **15–18.** *Misifulgur sula* (Olsson, 1931). Caleta Mero, Talara Basin, northern Peru. Early Miocene. **15.** PRI 2104. Holotype. Apertural view. Partially decorticated, partially an internal mold. Length 43.3 mm. **16.** PRI 2104. Abapertural view. **17.** PRI 2105. Paratype. Apertural view. Length 27.4 mm. **18.** PRI 2105. Abapertural view. Partially decorticated. **19, 20.** *Misifulgur macneili* new species. East Pisco Basin, south-central Peru. Early Miocene. **19.** UWBM 104230. B8378. Paratype. Abapertural view. Siphonal canal and portion of last whorl missing. Length 47.2 mm. **20.** UWBM 98670. B8376. Holotype. Abapertural view. Portion of siphonal canal missing. Partially an internal mold. Length 44.8 mm. **21–30.** *Misifulgur cruziana* (Olsson, 1932). **21.** PRI 2307. Holotype. Quebrada de la Cruz, Progreso Basin, northern Peru. Early Miocene. Apertural view. Anterior is missing. Length 28.2 mm. **22.** UWBM 98656. B8316, East Pisco Basin, south-central Peru. Middle Miocene. Outer lip: fragment of smooth inside of posterior portion (upper half) and mold of spirally corded exterior of anterior portion (lower half). Leading edge of outer lip at right. Length of fragment + mold is 28.7 mm. **23.** UWBM 98652. B8316. Abapertural view. Anterior end missing, largest visible whorl partially decomposed/dissolved. Length 23.7 mm. **24.** UWBM 98656. Abapertural view. Length 55.2 mm. **25.** UWBM 98652. Close-up of mammillate deviated protoconch. **26.** UWBM 98656. Lateral view. Partially an internal mold at center left of image. **27.** UWBM 98666. B8371, East Pisco Basin, south-central Peru. Middle Miocene. Apertural view. Portion of siphonal canal missing, partially abraded by wind-blown sand. Length 64.5 mm. **28.** MUSM INV 194. B8313, East Pisco Basin, south-central Peru. Middle Miocene. Apertural view of partly crushed specimen. Length 48.2 mm. **29.** UWBM 98666. Lateral view. Partially an internal mold at left on spire. **30.** UWBM 98654. B8316. Abapertural view showing mammillate deviated protoconch. Anterior end missing. Anteriormost whorls decorticated or with exposed internal mold. Length 19.3 mm.

Remarks: Specimens of *Misifulgur macneili* new species are less constricted towards the base and have a narrower sutural ramp than those of *M. sula*, which otherwise is the species of *Misifulgur* that *M. macneili* most resembles. The anterior and mid-whorl spiral cords on both *M. macneili* and *M. sula* are less flattened, narrower, and with wider interspaces than on specimens of *M. cruziana* and *M. montemarensis* (see below).

At most localities, specimens of *Misifulgur macneili* and *M. cruziana* occur together. The latter species is highly variable in terms of spire height, width and slope of the sutural platform, and the onset of spiral cord obsolescence on later whorls. *Misifulgur macneili* is not thought to be a variant of *M. cruziana* for the following reasons. First, specimens of *M. macneili* have six or seven spiral cords anterior to the shoulder on spire whorls; all variants of *M. cruziana* have three or four. Second, the posterior spiral cords on specimens of *M. macneili* flatten but do not fade to obsolescence on later whorls. On all variants of *M. cruziana*, some posterior spiral cords do disappear. Lastly, the shoulder on specimens of *M. macneili* is barely angled, whereas shoulders on the least tabulate variants of *M. cruziana* have a distinct angulation at the shoulder that coincides with a strong spiral cord.

Misifulgur macneili occurs at two closely situated sites near the base of the Chilcatay depositional sequence in coarse-grained sandstone and fine gravel (Figure 1, middle inset). Specimens are part of a diverse molluscan assemblage that includes gastropods overgrown with bryozoans or small colonies of barnacles. The *Misifulgur*-bearing horizon is correlative with nearby oyster banks that lap against outcrops of crystalline paleo-basement. A latest Oligocene age is inferred from the stratigraphic position of the *Misifulgur* specimens close to the transgressive base of the Chilcatay depositional sequence (DeVries, 1998). The youngest specimens were collected from within the mid-section of the type section of the Chilcatay Formation. Their age is inferred to be about 18 Ma, based on diatoms in overlying tuffaceous and diatomaceous sandstone (DeVries, 1998).

***Misifulgur cruziana* (Olsson, 1932)**
(Figures 21–37)

Acanthiza (*Chorus*) *sula cruziana* Olsson, 1932: 185, pl. 20, fig. 7.

(?) *Chorus cruzianus* (Olsson).—Marks, 1951: 23, 30, also unpaginated figs 5, 7.

(?) *Fasciolaria*? [sic] sp. Marks, 1951: 28, also unpaginated fig. 7.

Diagnosis: Shell length to 120 mm. Sutural ramp planar, sloping anteriorly five to 45 degrees from suture. Primary spiral cord on shoulder strong or keeled on large specimens.

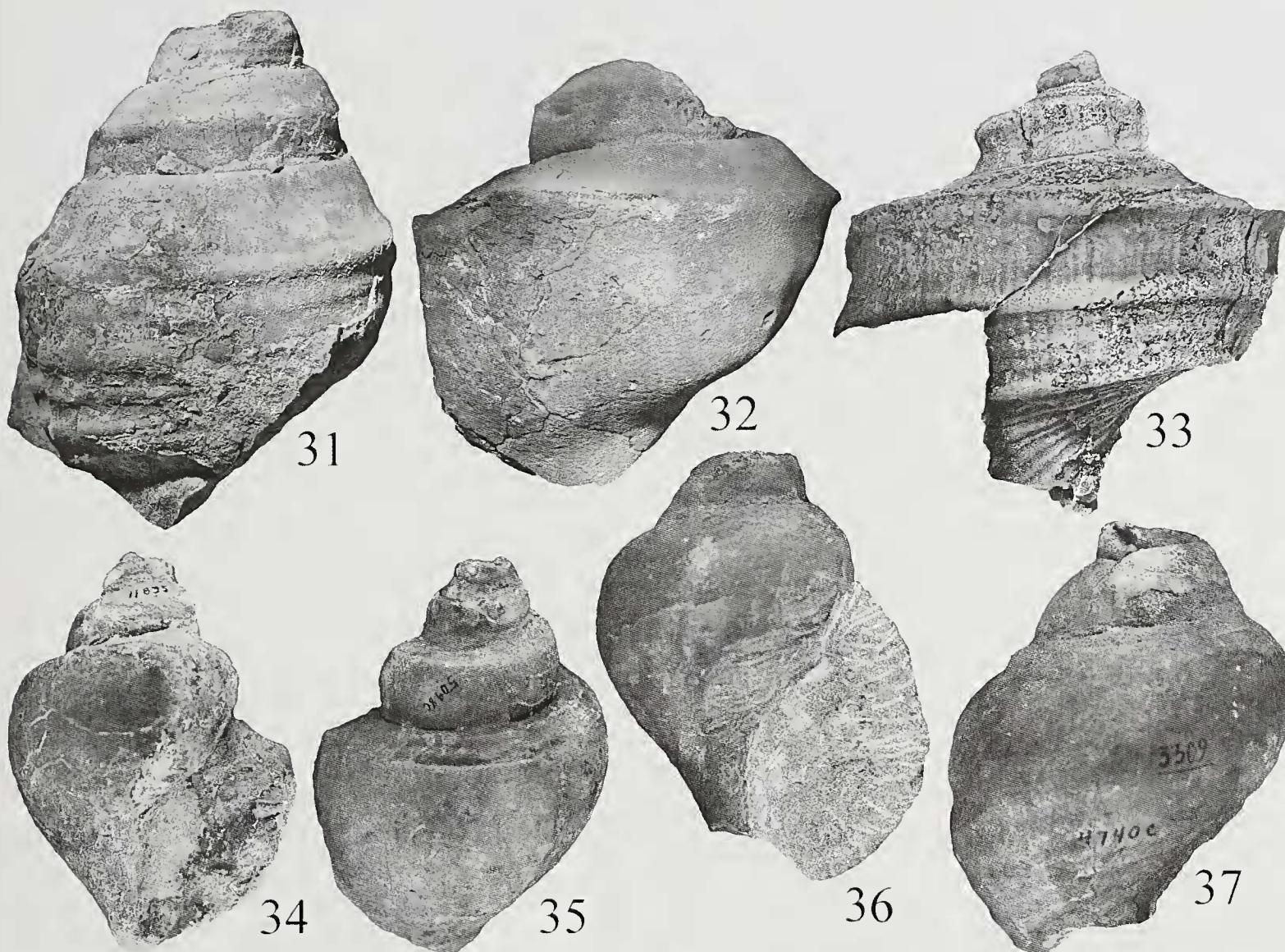
Description: Estimated shell length to 120 mm, fusiform in small specimens, moderately to strongly constricted with inflection about 60 percent of distance

from last-whorl suture to anterior end; later whorls posteriorly inflated, deeply constricted, and strongly tabulate in some larger specimens. Shell very thin medially between shoulder and base. Protoconch mammillate, smooth, at least two whorls, slightly deviated. Teleoconch with five whorls. Spire moderately elongate, sutures moderately impressed. Sutural ramp planar, sloping anteriorly 45 degrees from suture on small and medium-sized specimens; on large specimens, sutural ramp planar to concave, sloping anteriorly five to 45 degrees from suture. Shoulder angulate, defined by rounded primary spiral cord, keeled on some large specimens. Axial sculpture of orthocline radial growth lines, often bent adaperturally at suture. Earliest spire whorls with smooth sutural ramp and three or four primary spiral cords anterior to shoulder. Last whorl on small specimens with about 17 broad primary spiral cords between base and shoulder, with posteriormost three diminished, flattened, and more widely spaced. Primary interspaces U-shaped to flat-bottomed, becoming as wide as primary cords adapically towards shoulder, rarely with an intercalated secondary spiral cord. Either side of shoulder sometimes with closely spaced subdued secondary spiral cords; sutural ramp with primary spiral cords absent or with one spiral cord situated medially or close to suture. Larger specimens with broad smooth concavity bounded by shoulder and primary spiral cord near midpoint of whorl. Anterior half of last whorl on large specimens with about 12 spiral cords, spaced more closely towards base. Aperture ovate and elongate in small specimens, quadrate in large specimens. Siphonal canal about 20 percent of shell length, recurved abaxially, broadly open. Columellar or parietal callus absent. Inner lip without plications. Siphonal fasciole obsolete. Inside of outer lip smooth.

Type Material: PRI 2307, holotype, L (28.2), W 26.1.

Type Locality: Quebrada de La Cruz, northern Peru (Figure 1, upper inset), early Miocene.

Other Material Examined: MUSM INV 190, B8316, middle Miocene, L (29.7), W (28.8); MUSM INV 191, B8316, L (29.2), W 17.7; MUSM INV 192, B8316, L (28.9), W 28.4; MUSM INV 193, B8316, L 62.0, W (47.1); MUSM INV 194, B8313, middle Miocene, L (48.2), W 34.1; MUSM INV 195, B8305, early Miocene, L (28.2), W (26.1); MUSM INV 196, B8371, middle Miocene, L (54.4), W 40.0; MUSM INV 197, B8371, L (43.5), W 31.3; MUSM INV 198, B8371, L (50.1), W (53.4); MUSM INV 199, B8358, early Miocene, L (39.5); UWBM 98652, B8316, L (23.7), W 19.0; UWBM 98653, B8316, L (29.4), W 28.0; UWBM 98654, B8316, L (19.3), W 16.6; UWBM 98655, B8316, L 30.9, W (19.9); UWBM 98656, B8316, L (53.0), W 33.6; UWBM 98657, B8316, L (57.3), W 47.3; UWBM 98658, B8364, middle Miocene, L (47.0), W 34.7; UWBM 98659, B8362, middle Miocene, L (48.0), W (31.2); UWBM 98660, B8362, L (28.2), W (25.5); UWBM 98661, B8372, middle Miocene, L (37.8), W (46.5); UWBM 98662, B8305, L (65.3), W (52.5); UWBM 98663,



Figures 31–37. *Misifulgur* species. **31–33.** *Misifulgur cruziana* (Olsson, 1932). Large specimens from East Pisco Basin, south-central Peru. Late Oligocene to early Miocene. **31.** UWBM 104232, B8361. Abapertural view. Partially decorticated. Length 83.6 mm. **32.** UWBM 104231, B8361. Abapertural view. Internal mold. Length 63.1 mm. **33.** UWBM 104233, B8358. Abapertural view. Rubber cast of external mold in concretion. Length 61.0 mm. **34–37.** *Misifulgur cruziana* (Olsson, 1932). Molds from the Progreso Basin of southwestern Ecuador (Marks, 1951). **34.** PRI 68827, PRI locality 5098C. Progreso Formation, middle to lower Miocene. Apertural view. Internal mold, most of siphonal canal missing. Image taken without ammonium chloride. Length 107 mm. **35.** PRI 68827. Abapertural view. **36.** PRI 68826, PRI locality 4740C. Upper Tosagua Formation, lower Miocene. Apertural view. Internal mold, anterior end missing. Image taken without ammonium chloride. Length 79 mm. **37.** PRI 68826. Abapertural view.

B8305, L (34.6), W (26.4); UWBM 98664, B8376, early Miocene, L (25.0), W (23.0); UWBM 98665, B8376, L (24.7), W 18.0; UWBM 98666, B8371, L (64.5), W 46.3; UWBM 98667, B8371, L (48.0); UWBM 98668, B8371, L (69.4), W (55.6); UWBM 98669, B8358, L (48.1), W (44.4); UWBM 98676, B8366, late Miocene, L (61.4), W (42.8); UWBM 104231, B8361, early Miocene, L (63.1), W (62.7); UWBM 104232, B8361, L (83.6), W (62.5); UWBM 104233, B8358, L (61.0), W (57.0); UWBM 104234, B8363, late middle Miocene, L (78.9), W 65.3; PRI 68826, L (79), W 64; PRI 68827, L (107), W 78. Also B8359, B8365, B8369, B8370, B8333, B8374, B8375, B8377, B8343, B8379.

Distribution: Aquitanian, Chilcatay depositional sequence, south-central Peru; lower Zorritos/Heath formations, northern Peru. Dos Bocas Member, Tosagua For-

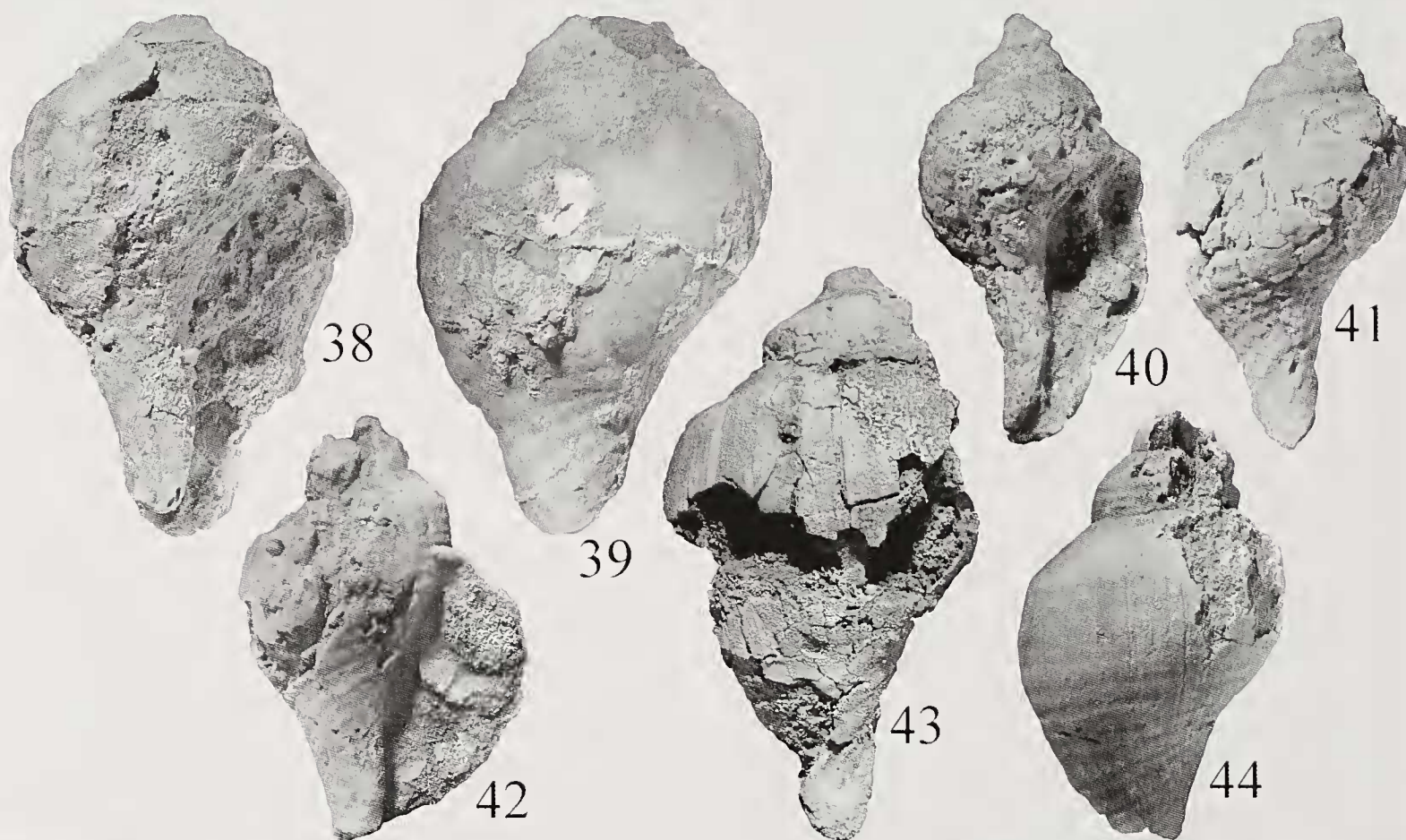
mation, Progreso Basin, southwestern Ecuador. Burdigalian to early Tortonian, Chilcatay and Pisco depositional sequences, south-central Peru. Tosagua and Progreso formations, Progreso Basin, southwestern Ecuador.

Remarks: The incomplete holotype of *Misifulgur cruziana* from northern Peru is identical with more complete medium-sized specimens from the East Pisco Basin. Specimens of *M. cruziana* from south-central Peru include examples with paucispiral, deviate, mammillate protoconchs (Figures 23, 25, 30), a complete siphonal canal (Figure 26), and highly variable specimens much larger than the northern Peruvian holotype (Figures 31–33), in which the last whorls may be broader, more inflated posteriorly, and with keeled shoulders bounded anteriorly and posteriorly by broad, shallow, smooth concavities (Figures 29, 33).

Misifulgur cruziana was the most common medium-sized to large carnivorous gastropod on the Peruvian continental shelf from the early to early late Miocene, living far enough offshore for sardine scales to be embedded in the sandy matrix, i.e., at water depths of 30 meters or greater (DeVries and Percy, 1982). The youngest specimen was found near the base of upper Miocene outcrops at Cerro Blanco, in the Río Ica valley near Ocucaje (UWBM 98676), where medium-grained sandstone lies nonconformably upon a rugged basement of crystalline basement rock (locality B8366). An ash bed (DV 494-5Snee) 68 meters above the *Misifulgur*-bearing bed yielded an ^{40}Ar - ^{39}Ar date of 6.85 ± 0.07 Ma (L. Snee, United States Geological Survey, written communication, 1987), consistent with a late late Miocene age indicated by diatoms from nearly the same horizon (H. Schrader, University of Bergen, Norway, written communication, 1988) and other ^{40}Ar - ^{39}Ar ash dates from correlative same strata (Brand et al., 2011).

A buccinid mold (PRI 68826; figs 36, 37) attributed by Marks (1951) to *Misifulgur cruziana* (cited as *Chorus cruziana*) was collected in southwestern Ecuador, 1.75 kilometers west of Carrizal (estimated locality: $02^{\circ}06'S$,

$80^{\circ}27'30''W$, based on comparison of data obtained from MapCarta and Google Earth). A second mold (PRI 68827; figs 34, 35), identified as *Fasciolaria*? sp. [sic] by Marks (1951) but similar to *Misifulgur* molds from Peru and Ecuador, was collected at IPC locality 11895 (P. Plocic, Paleontological Research Institution, written communication, 26 May 2016; additional locality data are unavailable). According to Marks (1951), the Carrizal specimen was collected from cross-bedded sandstones of inner shelf origin from the upper Subibaja Formation, assigned an early Miocene age based on correlations with mollusks in Peru and foraminifera identified by R. M. Stainforth (1948). The Carrizal locality is more recently mapped into the lower Miocene Dos Bocas Member of the Tosagua Formation (Longo and Baldock, 1982). The "*Fasciolaria*" mold (PRI 68827), as well as additional specimens of "*Chorus cruziana*" cited by Marks (1951), were collected from the marine to brackish-water, middle to upper Miocene Progreso Formation (Marks, 1951); its age is supported by more recent authors (Longo and Baldock, 1982). Both Ecuadorian molds have a shape that falls within the broad range shown by Peruvian specimens.



Figures 38–44. *Misifulgur montemarensis* new species. Late Miocene. **38.** UWBM 98672, B8360. Holotype. Saeaco Basin, southern Peru. Apertural view. Shell material partially dissolved, internal mold partially visible. Length 67.9 mm. **39.** UWBM 98672. Abapertural view. Most of spire missing. **40.** UWBM 98674, B8373. Paratype. Saeaco Basin, southern Peru. Apertural view; note mammillate protoconch. Shell material partially dissolved. Length 26.4 mm. **41.** UWBM 98674. Abapertural view. Shell material partially dissolved. **42.** UWBM 98673, B8373. Paratype. Apertural view. Portion of siphonal canal and spire missing, partially an internal mold. **43.** UWBM 98675, B8359. East Pisco Basin, south-central Peru. Abapertural view. Portions of last whorl missing. Length 77.2 mm. **44.** UWBM 98673. Abapertural view.

***Misifulgur montemarensis* new species**

(Figures 38–44)

Diagnosis: Shell length to 110 mm, fusiform, weakly constricted towards base. Sutural ramp weakly planar, sloping anteriorly 50 to 70 degrees from suture. Spiral sculpture of about 16 very broad primary spiral cords between base and shoulder, diminished in strength near shoulder.

Description: Shell to 110 mm long, fusiform, weakly constricted, inflection about 60 percent distance from last-whorl suture to anterior end; shell very thin medially. Protoconch mammillate, smooth, at least two whorls, slightly deviated. Teleoconch of four to five whorls. Spire moderately elevated, sutures weakly impressed. Sutural ramp weakly planar, sloping anteriorly 50 to 70 degrees from suture. Shoulder with small inflection and weak primary spiral cord. Axial sculpture of fine, closely spaced, orthocline, radial growth lines. Spiral sculpture on last whorl of about 16 broad, low, primary spiral cords between base and shoulder, diminishing in strength near shoulder. Primary interspaces broadly U-shaped, narrower than primary spiral cords, without intercalated spiral elements. Spire whorls with sutural ramp and five primary spiral cords, one on sutural ramp and three to four from shoulder anteriorward. Aperture elongate, ovate. Siphonal canal 20 percent of shell length, narrow, open, nearly straight. Columellar and parietal callus absent or nearly so; inner lip without plications. Siphonal fasciole obsolete. Inside of outer lip smooth.

Type Material: (all late Miocene): UWBM 98672, B8360 (type locality), holotype, L (67.9), W 45.4; UWBM 98673, B8373, paratype, L (34.6), W 23.2; UWBM 98674, B8373, paratype, L 26.4, W (13.9).

Type Locality: B8360, eastern flank of Montemar hills, between Lomas and Sacaco, southern Peru. Late Miocene, about 6–8 Ma (Figure 1, lower inset).

Other Material Examined (all late Miocene): MUSM INV 201, B8368, L 102.8, W (49.0); MUSM INV 202, B8367, L (72.9), W (39.7); UWBM 98675, B8359, L (77.2), W (42.2).

Distribution: Late Miocene, southern Peru.

Etymology: Named for the Montemar paleo-island near Lomas, Peru, in the lee of which *Misifulgur*-bearing upper Miocene tuffaceous sands were deposited.

Remarks: Specimens of *Misifulgur montemarensis* have planar and steeply dipping sutural ramps and poorly defined shoulders, even on the largest specimens. Primary spiral cords on specimens of *M. montemarensis* are broader and lower than those on specimens of the round-shouldered early Miocene *M. sula* and have narrower interspaces.

The types of *Misifulgur montemarensis* were found in shoreface sandstone on the lee side of a granitic paleo-

island – Montemar. A late Miocene age is inferred from 8-Ma ^{40}K - ^{40}Ar -dated ash beds lower in the section (Muizon and DeVries, 1985). Other specimens (MUSM INV 201, MUSM INV 202) were found near Nazca on the lee side of a paleo-peninsula (Cerro Huaricangana; see DeVries, 1988) in littoral sandstones 20 meters above an ash bed (DV 528-1Snee) with a late Miocene ^{40}Ar - ^{39}Ar date of 7.51 ± 0.05 Ma (L. Snee, written communications, 1987).

DISCUSSION

Misifulgur dockeryi is the oldest species of its genus by ten million years, so it might be that the Gulf of Mexico, home to other Paleogene buccinoids (MacNeil and Dockery, 1984), was home to the first *Misifulgur*. By the latest Oligocene or earliest Miocene, when no physical barrier had yet separated the Pacific and Atlantic Oceans (Collins et al., 1996), *M. sula* and *M. cruziana* had become established in southwestern Ecuador, northwestern Peru (Olsson, 1931, 1932), and for the latter species, south-central Peru. A similar pattern of distribution characterized the Caribbean genus, *Muracypiraea* Woodring, 1957, for which early Miocene northern and southern Peruvian species constituted southern hemispheric outliers (DeVries et al., 2006).

A case against dispersal and in favor of convergence of the Miocene western South American species with an unrelated Gulf Coast Oligocene species could be made based on the absence of Central American records for *Misifulgur*. The buccinids herein referred to *Misifulgur*, however, are rare in northern Peru (three specimens) and southwestern Ecuador (two specimens), indicating that their absence in Miocene deposits of Central America may reflect a Miocene scarcity of individuals or a modern scarcity of preserved paleo-habitat. The issue of convergence versus dispersal will not be resolved until *Misifulgur* is found in Central America or a plausible Oligocene ancestral buccinid is found in western South America.

HISTORICAL BIOGEOGRAPHICAL CONTEXT FOR BUCCINIDS ON THE PERUVIAN SHELF

The modern Peruvian Faunal Province (Dall, 1909; Tarazona et al., 2003), which includes the present-day coastline of the East Pisco and Sacaco basins but not the Talara nor Progreso basins, is inhabited at intertidal and shallow subtidal depths by medium-sized carnivorous muricid gastropods of the genera *Acanthina*, *Concholepas* Lamarek, 1801, *Stramonita* Schumacher, 1817, and *Xanthochorus* Fischer, 1884 (Alamo and Valdivieso, 1997; Guzmán et al., 1998). At inner shelf depths, *Stramonita* and *Xanthochorus* occur together with the carnivorous / scavenging buccinid, *Solenosteira fusiformis* and, off southern Peru, the buccinid, *Aeneator fontainei*, the former with a distribution northward into the Panamic Faunal Province and the latter with southern ocean affinities (Laudien et al., 2007; Araya, 2013; S.V. Mogollón, written communication, 2008). On the Chilean shelf, gastropod

predators include members of the muricid genus *Trophon* Montfort, 1810, the muricid *Chorus giganteus* (Lesson, 1831) (McLean and Andrade, 1982; Gajardo et al., 2002), and *A. fontainei*.

During the early to late Pliocene, soft-bottom substrates of the Peruvian Faunal Province at comparable shallow depths were occupied by the same genera of medium-sized muricids as would be present during the Quaternary, although usually the genera were represented by species now extinct (DeVries, 1995; 2000; 2003; 2005a). Some muricid genera (*Concholepas*, *Chorus*, *Trophon*, *Xanthochorus*) had more expansive distributions, ranging from Chile to Cabo Blanco, northern Peru (Herm, 1969; DeVries, 1986; 1995; 1997; 2005b; 2007a).

From the latest Oligocene to the early late Miocene, *Misifulgur*, especially *M. cruziana*, is inferred from its abundance to have been the predominant medium-sized to large carnivorous neogastropod on the Peruvian shelf. Muricids were rare and small (DeVries, 2005b). A variety of neogastropods inhabited Mioene shelf substrates of Ecuador's Progreso Basin, according to Marks (1951), including *Misifulgur*, *Conus* spp., *Terebra* spp., and turrids, but notably not muricids. During the late Miocene, the youngest species of *Misifulgur*, *M. montemarensis*, appeared at inner shelf depths along the southern Peruvian coast, and then, at about 6 Ma, became extinct, an event approximately coinciding with the northward expanding range of a similarly sized, shelf-dwelling, carnivorous neogastropod, the Chilean muricid, *Chorus frassinetti* DeVries, 1997, as well as the appearance of the smaller Peruvian trophinines, *Xanthochorus stephanicus* DeVries, 2005 and *X. ochuroma* DeVries, 2005 (DeVries, 2005a).

CONCLUSIONS

Buccinids in *Misifulgur* new genus probably evolved along the Gulf Coast of the United States during the Oligocene. *Misifulgur* did not experience the same Neogene diversification in the Atlantic realm as other buccinid genera, but before the latest Oligocene evidently passed into the tropical eastern Pacific Ocean, where populations found a niche on soft substrates of the continental shelf from southwestern Ecuador to southern Peru. *Misifulgur cruziana* became the most abundant and perhaps largest carnivorous gastropod inhabiting the southern Peruvian sandy inner shelf during the early and middle Miocene. By the late Miocene, only *M. montemarensis* new species remained, living close to the shoreline on protected sandy substrates. The demise of *M. montemarensis* and thereby the extinction of *Misifulgur* coincided with the late Miocene to early Pliocene advent and diversification of the morphologically similar, shelf-dwelling, carnivorous muricid genus, *Chorus*, as well as the trophinine genus, *Xanthochorus*.

ACKNOWLEDGMENTS

I would like to thank David Dockery (Office of Geology, Mississippi Department of Environmental Quality) for

the loan of Oligocene specimens from the Gulf Coast and curators of the Paleontological Research Institution (PRI), the Academy of Natural Science of Philadelphia, and the United States National Museum of Natural History for the loan of material. Staff at PRI (Greg Dietl, Leslie Skibinski, Page Plocic) were very accommodating during a visit to Ithaca. Valentín Mogollón (Universidad Nacional Federico Villarreal, Lima, Peru) offered invaluable information on the modern Peruvian molluscan fauna. The manuscript was improved by constructive suggestions from Anton Oleinik (Florida Atlantic University, Boca Raton, Florida) and Sven Nielsen (Universidad Austral, Valdivia, Chile).

LITERATURE CITED

- Alano V., V., and V. Valdivieso M. 1997. Lista sistemática de moluscos marinos del Perú. Instituto del Mar del Perú, Callao, 183 pp.
- Anton, H.E. 1838. Verzeichniss der Conchylien welche sich in der Sammlung von Herbert Eduard Anton befinden. H.E. Anton, Halle, xvi + 110 pp.
- Araya, J.F. 2013. A new species of *Aeneator* Finlay, 1926 (Mollusca, Gastropoda, Buceinidae) from northern Chile, with comments on the genus and a key to the Chilean species. *ZooKeys* 257: 89–101.
- Arnold, R. 1908. Descriptions of new Cretaceous and Tertiary fossils from the Santa Cruz Mountains, California. *Proceedings of the United States National Museum* 34(1617): 345–390.
- Beu, A.G. 2010. Neogene tonnoidean gastropods of tropical and South America: Contributions to the Dominican Republic and Panama paleontology projects and uplift of the Central American Isthmus. *Bulletins of American Paleontology* 377–378: 1–550.
- Beu, A.G. and W.O. Cernohorsky. 1986. Taxonomy of gastropods of the families Ranellidae (= Cynatiidae) and Bursidae. Part 1. Adoption of Ranellidae, and review of *Linatella* Gray, 1857. *New Zealand Journal of Zoology* 13: 241–266.
- Blainville, H. 1832. Disposition méthodique des espèces Récentes et fossiles des genres pourpre, ricinule, licorne et concholepas de M. de Lamarck. *Nouvelles Annales du Museum d'Histoire Naturelle* 1: 189–190, 220–226, 230, 236–248.
- Brand, L., M. Urbina, A. Chadwick, T.J. DeVries, and R. Esperante. 2011. High-resolution stratigraphic framework for the remarkable fossil cetacean assemblage of the Miocene/Pliocene Pisco Formation. *Journal of South American Earth Sciences* 31(4): 414–425.
- Coleman, J.L. 1983. The Vicksburg Group carbonates - a look at Gulf Coast Paleogene carbonate banks. *Gulf Coast Association of Geologists Transactions* 33: 257–268.
- Collins, L.S., A.G. Coates, W.A. Berggren, M.-P. Aubry, and J. Zhang. 1996. The late Miocene Panama isthmian strait. *Geology* 24: 687–690.
- Conrad, T.A. 1848. Observations on the Eocene formation, and descriptions of one hundred and five new fossils of that period, from the vicinity of Vicksburg, Mississippi, with an appendix. *Academy of Natural Sciences of Philadelphia, Proceedings* 3: 280–299.
- Dall, W.H. 1895. Report on Mollusca and Brachiopoda dredged in deep water, chiefly near the Hawaiian Is., with illustrations of hitherto unfigured species from North-West

- America. Proceedings of the United States National Museum 17(1032): 675–733.
- Dall, W.H. 1909. Report on a collection of shells from Peru, with a summary of the littoral marine Mollusca of the Peruvian zoological province. Proceedings of the United States National Museum 37(1704): 147–294.
- DeVries, T.J. 1986. The geology and paleontology of tablazos in northwest Peru [Ph.D. Thesis]. The Ohio State University, Columbus, 964 pp.
- DeVries, T.J. 1988. Paleoenvironments of the Pisco Basin. In: R.B. Dunbar and P.A. Baker (eds.), Cenozoic geology of the Pisco Basin: a guidebook to accompany a regional IGCP 156 field workshop, "Genesis of Cenozoic phosphorites and associated organic-rich sediments, Peruvian continental margin." Rice University, Houston, Texas, pp. 41–50.
- DeVries, T.J. 1995. *Concholepas* Lamarck, 1801 (Neogastropoda: Muricoidae): A Neogene genus native to South America. The Veliger 38: 284–297.
- DeVries, T.J. 1997. A review of the genus *Chorus* Gray, 1847 (Gastropoda: Muricidae) from western South America. Tulane Studies in Geology and Paleontology 30: 125–147.
- DeVries, T.J. 1998. Oligocene deposition and Cenozoic sequence boundaries in the Pisco Basin (Peru). Journal of South American Earth Sciences 11: 217–231.
- DeVries, T.J. 2000. Two new Neogene species and the evolution of labral teeth in *Concholepas* Lamarck, 1801 (Neogastropoda: Muricoidea). The Veliger 43: 43–50.
- DeVries, T.J. 2002. Patterns of diversity in Cenozoic marine mollusks from the Peruvian Province. Geological Society of America, Abstracts with Programs 34(5): A–39.
- DeVries, T.J. 2003. *Acanthina* Fischer von Waldheim, 1807 (Gastropoda: Muricidae), an oceanic genus endemic to South America. The Veliger 46: 332–350.
- DeVries, T.J. 2005a. The late Cenozoic history of *Xanthochorus* Fischer, 1884 (Gastropoda: Muricidae) in western South America. The Veliger 47: 259–276.
- DeVries, T.J. 2005b. Late Cenozoic Muricidae from Peru: Seven new species and a biogeographic summary. The Veliger 47: 277–293.
- DeVries, T.J. 2007a. Three new Pliocene species of *Stramonita* Schumacher, 1817 (Muricidae: Rapaninae) from western South America and the evolution of modern *Stramonita chocolata* (Duclos, 1832). The Veliger 48: 247–259.
- DeVries, T.J. 2007b. Cenozoic Turritellidae (Gastropoda) from southern Peru. Journal of Paleontology 81: 331–351.
- DeVries, T.J., L.T. Groves, and M. Urbina. 2006. A new early Miocene species of *Muracypira* Woodring, 1957 (Gastropoda: Cypracidae) from the Pisco Basin of southern Peru. The Nautilus 120: 101–105.
- DeVries, T.J. and W.G. Percy. 1982. Fish debris in sediments of the upwelling zone off central Peru: a late Quaternary record. Deep-Sea Research 28(1A): 87–109.
- DeVries, T.J. and H. Schrader. 1997. Middle Miocene marine sediments in the Pisco Basin (Peru). Boletín de la Sociedad Geológica del Perú 87: 1–13.
- Engelhardt, D.W., and G.D. Wood. 1993. Palynology of the Heath Formation (Miocene) from the Progreso Basin, Peru. AAPG Bulletin 77: 316.
- Fischer von Waldheim, G. 1807. Museum Démidoff, ou, Catalogue systématique et raisonné des curiosités de la nature et de l'art. volume 3. Végétaux et animaux. Imperial University of Moscow, Moscow, ix + 330 pp., 6 pl.
- Fischer P. 1884. Manuel de conchyliologie et de paléontologie conchyliologique, ou Histoire naturelle des mollusques vivants et fossiles, part 7. Librairie F. Savy, Paris, pp. 609–688.
- Gajardo G., J.M. Cancino, and J.M. Navarro. 2002. Genetic variation and population structure in the marine snail *Chorus giganteus* (Gastropod: Muricidae), an overexploited endemic resource from Chile. Fisheries Research 55: 329–333.
- Gmelin, J.F. 1791. Caroli a Linnaci, Systema naturae per regna tria naturae, editio decima tertia, aucta, reformata, J.F. Gmelin (ed.). Volume 1, Part 6, Vermes. G. E. Beer, Leipzig, p. 3021–3910.
- Grant, U.S., IV, and H.R. Gale. 1931. Catalogue of the marine Pliocene and Pleistocene Mollusca of California and adjacent regions with notes on their morphology, classification, and nomenclature and a special treatment of the Pectinidae and the Turridae (including a few Miocene and Recent species). Memoirs of the San Diego Society of Natural History 1: 1–1036.
- Gray, J.E. 1847. A list of the genera of Recent Mollusca, their synonyms and types. Proceedings of the Zoological Society of London 15: 129–219.
- Gray, J.E. 1854. On the division of tenebrous gastropodous Mollusca into larger groups and families. Proceedings of the Zoological Society of London 21: 32–44.
- Guzmán, N., S. Saá, and L. Ortlieb. 1998. Catálogo descriptivo de los moluscos litorales (Gastropoda y Pelecypoda) de la zona de Antofagasta, 23°S (Chile). Estudios Oceanológicos 17: 17–86.
- Haas, O. 1942. Miocene molluscs from Costa Rica. Journal of Paleontology 16: 307–316.
- Hanna, G.D. and M.C. Israelsky. 1925. Contributions to the Tertiary paleontology of Peru. Proceedings of the California Academy of Sciences 14(2): 37–75.
- Herm, D. 1969. Marines Pliozän und Pleistozän in Nord- und Mittel-Chile unter besonderer Berücksichtigung der Entwicklung der Mollusken-Fauna. Zitteliana 2: 1–159.
- Higley, D.K. 2004a. The Talara Basin Province of northwestern Peru: Cretaceous-Tertiary total petroleum system. United States Geological Survey Bulletin 2206-A: 52 pp.
- Higley, D.K. 2004b. The Progreso Basin Province of Northwestern Peru and Southwestern Ecuador: Neogene and Cretaceous-Paleogene Total Petroleum Systems. U.S. Geological Survey Bulletin 2206-B: 25 pp.
- Lamarck, J.B. 1801. Système des animaux sans vertèbres, ou tableau général des classes, des ordres et des genres des ces animaux. Chez Deterville, Paris, 432 pp.
- Laudien, J., M.E. Rojo, M.E. Oliva, W.E. Arntz, and S. Thatje. 2007. Sublittoral soft bottom communities and diversity of Mejillones Bay in northern Chile (Humboldt Current upwelling system). Helgoland Marine Research 61: 103–116.
- Leon L., W.R., W. Rosell S., A.M. Aleman R., V.R. Torres B., and O. de la Cruz M. 2008. Estratigrafía, sedimentología y evolución tectónica de la Cuenca Pisco Oriental. Instituto Geológico, Minero y Metalúrgico (Perú), Boletín 27 (Serie D): 154 pp.
- Lesson, R.P. 1831. [1830–1831]. Mollusca, pp. 239–256. In: L.L. DuRoi, Voyage autour du monde : exécuté par ordre du roi, sur la corvette de Sa Majesté, la Coquille, pendant les années 1822, 1823, 1824, et 1825... Histoire Naturelle. Zoologie, vol. 2(1). Bertrand, Paris, 471 pp., 157 pl.
- Linnaeus, C. 1758. Systema naturae per regna tria naturae, secundum classes, ordines, genera, species, cum characteribus, differentiis, synonymis, locis (tenth edition). Stockholm, 824 pp.
- Lisson, C.I. 1925. Algunos fósiles de Perú. Boletín de la Sociedad Geológica del Perú 1: 23–30.

- Longo R. and J. Baldock. 1982. National geological map of the Republic of Ecuador (including Galápagos Province). Dirección General de Geología y Minas, Quito, Ecuador.
- MacNeil, F.S. and D.T. Dockery, III. 1984. Lower Oligocene Gastropoda, Scaphopoda, and Cephalopoda of the Vicksburg Group in Mississippi. Mississippi Geological Survey Bulletin 124: 1–415.
- Mansfield, W.C. 1935. New Miocene gastropods and scaphopods from Alauqua Creek Valley, Florida. Florida Geological Survey Bulletin 12: 64 pp.
- Marks, J.G. 1951. Miocene stratigraphy and paleontology of southwestern Ecuador. *Bulletins of American Paleontology* 33(139): 1–448.
- Martinez, E., J. Fernandez, Y. Calderon, W. Hermosa, and C. Galdos. 2005. Tumbes and Talara basins hydrocarbon evaluation. PeruPetro S. A., Lima, 130 pp.
- McLean, J.H. and H. Andrade V. 1982. Large archibenthal gastropods of central Chile: Collections from an expedition of the R/V Anton Bruun and the Chilean shrimp fishery. *Natural History Museum of Los Angeles County, Contributions in Science* 1982(342): 1–20.
- Montfort, D., de. 1810. *Conehyliologie systématique, et classification méthodique des coquilles*, volume 2. Schoell, Paris, 676 pp.
- Montoya, M., W. Garcia, and J. Caldas. 1993. Geología de los euadrangulos de Lomitas, Palpa, Nasca, y Puquio. Instituto Geológico, Minero y Metalúrgico (Perú), Boletín 53 (Serie A): 100 pp.
- Muizon, C., de and T.J. DeVries. 1985. Geology and paleontology of the Pisco Formation in the area of Sacaco, Peru. *Geologische Rundschau* 74: 547–563.
- Nelson, E.T. 1870. On the molluscan fauna of the later Tertiary of Peru. *Transactions of the Connecticut Academy Arts and Sciences* 2: 186–206.
- Oliveira, A.M., W.J. Zinsmeister, and S. Graciela Parma. 1994. *Peonza*: new gastropod genus from the middle Tertiary of Patagonia and Chile. *Journal of Paleontology* 68: 279–286.
- Olsson, A.A. 1922. The Miocene of northern Costa Rica. *Bulletins of American Paleontology* 9(39): 1–288.
- Olsson, A.A. 1931. Contributions to the Tertiary paleontology of northern Peru. Part 4, The Peruvian Oligocene. *Bulletins of American Paleontology* 17(63): 1–124.
- Olsson, A.A. 1932. Contributions to the Tertiary paleontology of northern Peru. Part 5, The Peruvian Miocene. *Bulletins of American Paleontology* 19(68): 1–272.
- d'Orbigny, A.D. 1839. *Voyage dans l'Amerique Méridionale...* exécuté pendant les années 1826, 1827... et 1833. Bertrand, Paris, pp. 425–488, pl. 63.
- Palacios M., O. 1994. Geología de los euadrangulos de Paita, Piura, Talara, Sullana, Lobitos, Quebrada Seca, Zorritos, Tumbes y Zarumilla. Instituto Geológico, Minero y Metalúrgico (Perú), Boletín 54 (Serie A): 1–190.
- Petuch, E.J. 2003. *Cenozoic seas: The view from eastern North America*. CRC Press, Boca Raton, Florida, 308 pp.
- Rafinesque, C.S. 1815. *Analyse de la nature, ou tableau de l'univers et des corps organisés*. Palermo, 223 pp.
- Risso, A. 1826. *Histoire naturelle des principales productions de l'Europe méridionale et particulièrement de celles des environs de Nice et des Alpes Maritimes*. Volume 4. Levrault, Paris, 439 pp., 12 pl.
- Röding, P.F. 1798. *Museum Boltenianum, sive, Catalogus cimeliorum e tribus regnis naturae quae olim collegerat Joa. Fried. Bolten: pars secunda continens conehylia sive testacea univalvia, bivalvia & multivalvia*. J.C. Trappii, Hamburg, 199 pp.
- Sehumacher, C.F. 1817. *Essai d'un nouveau système des habitations des vers testacés*. Schultz, Copenhagen, 287 pp.
- Stainforth, R.M. 1948. Applied micropaleontology in coastal Ecuador. *Journal of Paleontology* 22: 113–151.
- Tarazona, J., D. Guitierrez, C. Paredes, and A. Indocochea. 2003. Overview and challenges of marine biodiversity research in Peru. *Gayana* 67: 206–231.
- Vermeij, G.J. 1998. Generic revision of the Neogastropod family Pseudolividae. *The Nautilus* 111: 53–84.
- Vermeij, G.J. and T.J. DeVries. 1997. Taxonomic remarks on Cenozoic pseudolivid gastropods from South America. *The Veliger* 40: 23–28.
- Woodring, W.P. 1957. *Muracypraea*, new subgenus of *Cypraea*. *The Nautilus* 70: 88–90.
- Woodring, W.P. 1964. Geology and paleontology of Canal Zone and adjoining parts of Panama. Geology and description of mollusks (Gastropods: Columbelloidea to Volutidae). United States Geological Survey Professional Paper 306-C: 1–297.
- Zuñiga, F.J. and J. Cruzado C. 1979. Biostratigrafía del noroeste Peruano. *Boletín de la Sociedad Geológica del Perú* 60: 219–232.

APPENDIX

Locality numbers of the Burke Museum of Natural History and Culture (Bxxxx), and corresponding DeVries locality-sample numbers (DV xxxx-xx). dep. seq. = depositional sequence.

BS305, DV 377-3	SW wall of Quebrada Gramonal, near juncture with Río Ica; deltaic foresets and bottom-sets of coarse-grained sandstone. 14°45'45" S, 75°30'27" W. Chilcatay dep. seq., upper lower Miocene.
BS313, DV 420-1	S end of Filudo Depression; gray sandstone beds. 13°53'12" S, 76°07'15" W. Pisco dep. seq., middle Miocene.
BS316, DV 482-8	As for BS316, middle horizon of fossils.
BS333, DV 1320-1	Pampa Colorado, along road to Playa Peñon, indurated red sandstones. 14°25'59" S, 75°49'19" W. Pisco dep. seq., lower upper Miocene.
BS343, DV 3004-1	NW corner of Cerro Submarino, above unconformity. 14°34'36" S, 75°39'55" W. Lower Pisco dep. seq., middle Miocene.
BS358, DV 395-12	Two km W of Cerro La Virgen, north side of Comotrana-Carhuas road. 14°10'04" S, 76°07'05" W. Chilcatay dep. seq., lower Miocene.
BS359, DV 421a-1	N wall of Quebrada Huaricangana, across from small canyons on S wall. 14°57'08" S, 75°18'06" W. Pisco dep. seq., upper Miocene.

B8360, DV 430-1	Montemar, three km S of Lomas intersection; shell-rich bed near Panamerican Highway. 15°31'08" S, 74°48'43" W. Pisco dep. seq., upper Miocene.	B8370, DV 576-6	Slopes E of Quebrada Gramonal. 14°45'38" S, 75°30'21" W. Pisco dep. seq., lower upper Miocene.
B8361, DV 441-14	Lower part of measured type section of Chilcatay Formation, 90.8 meters above measured base, "skull horizon." 14°11'31" S, 76°06'56" W. Lower Chilcatay dep. seq., lower Miocene.	B8371, DV 579-1	South of Quebrada Gramonal, one km E of double-knobbed hill above Río Ica in faulted zone of basement blocks and <i>Turritella</i> -sandstone; bed just above marine mammal level. 14°46'30" S, 75°30'06" W. Pisco dep. seq., middle Miocene.
B8362, DV 451-2	W side of Filudo depression; anadartid-bearing coarse-grained sandstone bed at 21 meters in measured section. 13°57'19" S, 76°07'19" W. Lower Pisco dep. seq., middle Miocene.	B8372, DV 580-1	1.5 to two km ENE of B8371; white bed with mollusks. 14°46'55" S, 75°29'28" W. Pisco dep. seq., middle Miocene.
B8363, DV 482-7	Bowl between Cerro La Brujita and Cerro La Bruja on W side Río Ica valley; lowest continuous shell level, with large gastropods. 14°30'41" S, 75°40'00" W. Pisco dep. seq., upper middle Miocene.	B8373, DV 1348-1	E side of Montemar, near Panamerican Highway. 15°31'18" S, 74°48'57" W. GPS. Pisco dep. seq., upper Miocene.
B8364, DV 482-10	As for B8316, two meters above middle shell bed.	B8374, DV 1403-1	Slope E of Cerro Sombrero, 5 meters above angular unconformity. 14°05'49" S, 76°11'08" W. Basal Chilcatay dep. seq., uppermost Oligocene.
B8365, DV 484-6	Yesera de Amara, ledges and sandstone horizons on lower NE slopes of buttes. 14°35'38" S, 75°40'10" W. Lower Chilcatay dep. seq., uppermost Oligocene to lower Miocene.	B8375, DV 1611-3	Campsite at Ullujaya West, bowl-shaped depression. 14°34'52" S, 75°38'40" W. Lower Chilcatay dep. seq., uppermost Oligocene.
B8366, DV 494-1	Cerro Blanco on W side Río Ica. Mollusks 15 meters above base of measured section, five meters below disconformity. 14°25'22" S, 75°41'12" W. Pisco dep. seq., upper Miocene.	B8376, DV 1648-1	Valley SW of Cerro Colorado; southwest-facing flank. 14°22'25" S, 75°53'52" W. Chilcatay dep. seq., lower Miocene.
B8367, DV 528-3	S wall of Quebrada Huaricangana, third gulch from W; 40 meters above base of section near E ridge. Shell bed with diverse fauna. 14°57'47" S, 75°16'58" W. Pisco dep. seq., upper Miocene.	B8377, DV 2005-1	SE side of Laguna Seca, near top of hill, above tuffaceous white horizon. 14°33'28" S, 75°32'46" W. Pisco dep. seq., lower upper Miocene.
B8368, DV 536-1	S wall of Quebrada Huaricangana, 25 meters above base of exposed section; cross-bedded sandstone with scattered <i>in situ</i> mollusks. 14°57'11" S, 75°17'08" W. Pisco dep. seq., upper Miocene.	B8378, DV 2241-1	SE of Cerros Colorados, edge of tilted surface of alluvial boulders with W source. 14°22'46" S, 75°53'50" W. Lower Chilcatay dep. seq., uppermost Oligocene to early Miocene.
B8369, DV 573-3	Faulted slopes about 1–2 km E of Fundo Santa Rosa, massive sandstone with fish scales. 14°47'16" S, 75°30'22" W. Pisco dep. seq., middle Miocene.	B8379, DV 4076-1	SE Cerros Colorado, above angular unconformity. 14°22'55" S, 75°53'52" W. Lower Chilcatay dep. seq., uppermost Oligocene.
		DV 494-5Snee	As for B8366, but 82 m above base of measured section, ash bed, 6.85 ± 0.07 Ma. No Burke locality number.
		DV 528-1Snee	As for B8367, but 20 m above base of measured section, ash bed, 7.51 ± 0.05 Ma. No Burke locality number.